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WEB SITE OPTIMIZATION USING PAGE POPULARITY

A link-editing algorithm based on relative page popularity can automatically revise a Web site's page structure to create a substantially more effective information scheme.

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AND DIMITRIS MOURLOUKOS

University of Patras, Greece

n HTTP log file records every request that a server accepts, including information such as the date and time of the request, the client submitting it, the file requested, and so on.¹ This neat source of information establishes a basis for observations that can lead to improved overall performance for a given Web site. One of these observations, page popularity, is the subject of this article.

We examine how to define page popularity in a meaningful way and show how using page popularity to rearrange a Web site can lead to a substantially more accessible and more effective hypertext scheme. (In a similar vein, Golovchinsky has explored automatic methods of link construction based on feedback from users collected during browsing.²)

The notion of log file analysis is not new (see the sidebar, "Web Resources for Improving Navigation" on page 24), but our approach uses an analysis of relative page popularity to automatically reorganize the pages of a Web site. We have developed pilot software to perform these functions and show here that the resulting improvement in navigation boosted page accesses in five different Web sites.

DEFINING PAGE POPULARITY

One easy way to estimate a page's popularity is to count the accesses to this page based exclusively on a given log file. (See <http://www.w3.org/Daemon/User/Config/Logging.html> for all the http connection properties written to the log file.) However, counting these *absolute accesses* (AAs) from the log file can be misleading. A page close to the home page (the server's initial page) will probably have more absolute accesses, because it stands on a path between the home page and target pages located deeper in the HTML "tree", where the home page is the root, and every hyperlink to another page constitutes a parent-child relationship. (Because a child page might have several links toward one of its ancestors, the term "tree" is not wholly felicitous.)

To better examine a page's popularity, we could take the following factors into consideration:

- the depth of the page (how many steps it is from the home page), d ;
- the number of pages at the same depth as the page being examined, n ; and
- the number of references (hyperlinks) to this particular page from other pages of the server, r .

Let's assume there is a factor a that embraces all of these parameters. Then, we can coin a new term, *relative accesses* (RA), which we derive from the following equation:

$$RA = a * AA \quad (1)$$

Defining the Coefficient a

Because page depth d can detract from the popularity of a page, we can reasonably assume that coefficient a must be proportional to d . Likewise, the number of pages at the same depth, n_d , should be proportional to a because the larger the number of choices, the greater the significance of selecting a specific page. Of course, references from other pages, r , generally bolster page popularity, so r must be in inverse proportion to coefficient a .

Recent Web servers can be configured to track down Web pages that have links to any of their pages and store the addresses in what is called the *referrer log*. Most Web browsers support this feature and thus send the reference (link) to a server's page simultaneously with the browser's HTTP request.

Let r be an estimate based on the number of references from a server's pages to a page on the same server. The relation between a_i , d_i , n_i , and r_i —the values of a , d , n , and r for page i —should have the following form:

$$a_i = F(d_i, n_i, 1/r_i), i = 1 \dots K, \quad (2)$$

where K is the number of Web pages and F is a specific function that can be defined to reflect a user's behavior—what pages the user visits, in what order, for how long, and so on—during navigation to a specific Web site.

Link-Editing Software

We have developed pilot software, Soala Version 2.0,³ that reorganizes the links between pages according to criteria set by the Web server's administrator. In the following measurements, if the relative popularity of a given page exceeds the popularity of at least one ancestor page (a page with shorter distance to the home page, standing in its path), the software rearranges the links.

Soala can assess relative page popularity periodically (every week, for example). The most instructive of the metrics it calculates are

- AA—number of absolute accesses per page;
- RA—number of relative accesses per page;
- PT—mean page time, how much time a user spends on a specific page;
- UT—mean user time, how much time a user spends on the server every session; and
- NP—mean number of pages, how many different pages a user visits every session.

Soala reorganizes the links between pages according to criteria set by the Web server's administrator.

In our analyses, a new session begins when a user first accesses the Web site. All successive accesses belong to the same session provided that the interval between them does not exceed a given time threshold.

A simple version of our link-editing algorithm is "If any page has an RA higher than its parent, interchange it with its parent page. Repeat the previous step until every page has ancestors with higher RAs."

Case Study Definition

We applied this algorithm for a specific definition of factor a , to show how an awkward organization of a Web server can discourage Internet users and how link editing (based on relative accesses) can remedy the problem.

To ensure that our results would be as accurate as possible, we allowed only authenticated users with valid usernames and passwords to access the Web server for this case study. The authentication of users is not crucial for the link-editing algorithm; we introduced this requirement for evaluation purposes only. Furthermore, there were no references to our site from outside our server, so the value of parameter r was accurate. We carefully selected the group of users, as well as the pages, to facilitate the interpretation of the results.

According to our earlier discussion, one possible way of specifying coefficient a_i is

$$a_i = c_1 * d_i + c_2 * n_i / r_i \quad (3)$$

where c_1 and c_2 are constants whose values vary according to the structure of the Web site.

The definition of parameters c_1 and c_2 is definite-

ly a challenging issue. Currently, we know that c_1 and c_2 can significantly affect the algorithm's behavior, but we are still researching what values will boost its

WEB RESOURCES FOR IMPROVING NAVIGATION

Our approach to improving Web site navigation automatically reorganizes pages on the basis of relative page popularity. This represents a different objective from other tools and, therefore, it is possible to combine our approach with other methods.

On the Market

There are many HTTP log file statistical analyzers on the market. For example, see:

Analog Log Analyser

<http://www.statslab.cam.ac.uk/~sret1/analog/>

GwStat <http://dis.cs.umass.edu/stats/gwstat.html>

WebTrends <http://www.webtrends.com>

None of them, however, suggests any site rearrangement based on their statistical data.

There are also navigation tools that include guidelines on how to improve Web site navigation, usability, and appeal. For example, see:

Usable Web, "Web Architecture"

<http://usableweb.com/itcms/architecture.html>

Microsoft, "Improving Web Site Usability and Appeal"

<http://msdn.microsoft.com/workshop/management/planning/improvingsiteus.asp>

Web Developer's Virtual Library, "Navigation"

<http://www.stars.com/location/Navigation/>

But these tools do not work automatically. On the contrary, their effectiveness depends almost entirely on the administrator's judgment and experience in Web design.

Web site promotion tools focus on how to attract more visitors to a specific site, either by achieving higher scores in search-engine queries—

SiteOwner Link Exchange Site

<http://www.siteowner.com/>

Submit It! Announcement Service

<http://www.submit-it.com/>

Cyberguide to Search Engine Promotion

<http://www.rankthis.com/>

—or by participating in Web steerings, see:

WebRing <http://www.webring.org/>

Although these tools may be valuable, they do nothing about structure enhancement, which is the focus of our approach.

In the Research Community

To our knowledge, the scientific literature includes no other published work on the analysis of log files according to page popularity. There is, however, some work in related fields. For example, Czerwinski¹ proposes an author-oriented link management system to help authors ensure the consistency of their Web material whenever it is moved, deleted, or changed. This method focuses on informing the authors whenever their pages have incorrect links or trying to automatically repair broken links whenever possible.

Researchers have acknowledged the importance of the depth versus breadth in the arrangement of Web links—

K. Larson and M. Czerwinski, "Web Page Design: Implications of Memory, Structure, and Scent for Information Retrieval," *Proc. CHI '98: Human Factors in Computing Systems*, Addison-Wesley, Reading, Mass., 1998, pp. 25-32, available online at <http://research.microsoft.com/users/marcz/chi981.htm>

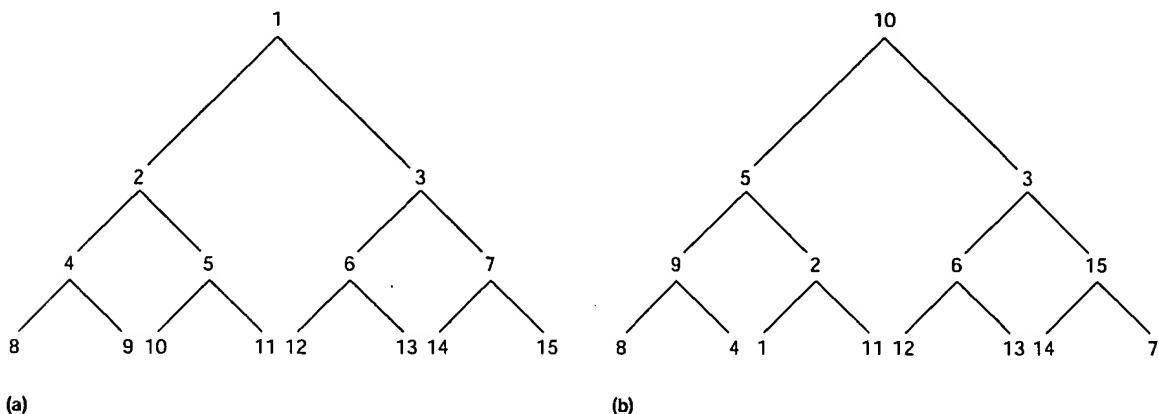
P. Zaphiris and L. Mie, "Depth vs Breadth in the Arrangement of Web Links," unpublished paper, available online at <http://www.csail.mit.edu/SHORE/bs04/index.html>,

—but no attempt has been made to connect this concept with user feedback as recorded in the log file.

In fact, good Web design is still an open research issue.^{2,3} Our approach represents a new way to gain better overall site performance.

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(a)

(b)

Figure 1. The link-editing algorithm reorganizes the pages in a Web site: (a) initial HTML structure and (b) revised HTML structure.

performance. For example, the higher we make the value of c_1 , the more vigorously the algorithm promotes pages deeper in the HTML structure. In some cases (when the value of c_1 is extremely high), this leads to volatile page arrangements: after each execution of the link-editing algorithm, a new rearrangement occurs. This is not a sound case. Any robust algorithm should achieve a balanced page arrangement, which remains unaffected by further executions of the algorithm, if the relative accesses don't change significantly. If we assign the value 1 to parameters c_1 and c_2 , we can rewrite equation 3 as

$$a_i = d_i + n/r_f$$

This is the case that we will examine.

First, from all PT and UT collected, we discarded time values that were too short or too long. A very short time represents the case of a user just clicking through a link to the next page. A very long time (one hour or more) represents the case of a user suspending navigation through the site for an external reason (an important e-mail or a meeting, for example) and returning much later to continue.

The site we evaluated comprised 15 pages (Page1, Page2, ..., Page15) organized into the binary tree structure depicted in Figure 1a. (Our algorithm also works on graph organizations; see the sidebar, "Link Editing for Graph Sites.") Page1, the initial home page, has two children, Page2 and Page3. For every n from 1 through 7, Page n has two children: Page $2n$ and Page $(2n+1)$. There is only one reference to each page (from its parent, with the exception of the home page); therefore parameter r has a value of 1 in every case. Our algorithm maintains the binary structure in its revision.

depicted in Figure 1b. What changes is the position of the pages within the structure. For instance, at the end of the link-editing procedure, Page2 occupies a position at a deeper level of the HTML tree than it did initially.

Table 1 (next page) summarizes the accesses to our system prior to link editing. For example, Page2 has a mean page time of 27 seconds, 97 absolute accesses, and 291 relative accesses (RA = $a * AA$, where $a = d + n/r = 1 + 2/1 = 3$).

As we can infer from Table 1, the initial HTML structure is rather inapt. It undervalues pages such as Page10, which exhibits significantly higher RA than other pages located closer to the home page. Table 2 summarizes the measurements based on the revised binary tree.

As we can easily see from Table 2, the new tree organization results in pages with a substantially different AA. The new sum of AAs

$$\begin{aligned} \text{SUM(AA)} &= \text{AA(Page1)} + \text{AA(Page2)} + \dots \\ &+ \text{AA(Page15)} \end{aligned}$$

exhibits a significant increase: the old SUM(AA) was 726; the new SUM(AA) is 866. The mean user time, UT, has also increased—from 112 seconds to 146 seconds—whereas PT fluctuates. Furthermore, the new page arrangement boosts the mean number of pages per user (NP) from 2.04 to 2.67, an increase similar to that for UT.

Even though these measurements are statistical, we can draw significant inferences. First, even a simple approach to link editing, based on relative page accesses, can significantly affect a user's behavior towards a particular Web site. Comparing Table 1 to Table 2 (next page), we can infer that we

Table 1. Measurement of accesses prior to link editing (Figure 1a).

Page	PT (seconds)	AA	RA
1	41	227	227
2	27	97	291
3	153	117	351
4	29	30	180
5	52	60	360
6	17	28	160
7	61	43	258
8	32	8	88
9	47	17	187
10	131	41	451
11	29	7	77
12	57	14	154
13	33	9	99
14	11	3	33
15	101	25	275

Table 2. Measurement of accesses after link editing: revised HTML structure (Figure 1b).

Page	PT (seconds)	AA	RA
1	43	11	121
2	28	37	222
3	151	160	480
4	31	8	88
5	49	103	309
6	17	43	258
7	63	16	176
8	30	12	132
9	45	47	282
10	121	326	326
11	32	13	143
12	62	21	231
13	35	12	132
14	13	2	22
15	97	55	330

increased the number of accesses to our site by 19 percent without changing the content of the pages. The 31 percent higher NP and UT indicate that the new organization seems to be more convenient and more attractive to potential users.

Another important aspect of this reorganization is that it can be automated: using a simple link-editing algorithm, we put the Web site structure in a more balanced and organized state (from a relative-access point of view).

APPLICATION RESULTS

The platform requirements of the Soala software are moderate. Any Pentium-based personal computer with 16 Mbytes of RAM is sufficient for the Soala program to run and calculate page popularities. The Web server we used in our research was the Apache 2.5.1 compiled for Solaris 2.6. Because the algorithm is independent of the Web server software, any Web server could serve the original or modified Web pages.

We applied our algorithm to several Web sites with totally different page structures (each created on an ad hoc basis) and calculated the percentage of the improvement in page accesses, shown in Table 3. Clearly, the more inapt an HTML structure, the more notably our link-editing algorithm improved it. To test how specific characteristics, such as contextual coherence among the pages, affected our algorithm's efficiency, we created sites that corresponded closely with the given requirements.

To further test the Soala software, we developed a Web site called Theleis. The objective of this new service is to help Greek Internet users find other services, products, and information that might be of interest to them. We built a series of 70 Web pages with variable information in their links and included two user prizes. So that we could take full advantage of Soala's capabilities, we left the architecture (how Web pages were linked, how many levels there should be, which page should go in

Table 3. Improvement in Web page accesses through link editing.

Site description	Number of nodes	AA improvement (%)
Inapt binary-tree page arrangement: Every page can be freely interchanged with its immediate relatives.	31	23
Inapt binary-tree page arrangement: Every page can be freely interchanged with its immediate relatives.	15	19
Graph HTML structure partially organized: Only the initial home page defined as a stable node.	31	12
Well-organized site: Initial home page and its children defined as stable nodes.	15	4

which level, and so on) rather open ended.

We did use some logical restrictions for the initial structure of Theleis, and we made some arbitrary decisions about what the site should look like. Then, we left the site to be accessed for 15 days. Next, we used the Soala link-editing algorithm to revise the initial HTML structure, and we retested the accessibility for the same time period (15 days, the same days of the week). As Table 4 shows, the results were encouraging. There was a 14 percent increase in absolute accesses. The 11 percent increase in the average page time shows that the site has become more attractive to users.

The links among pages constitute a "grafo" (a graph), and the access to the site is anonymous (no login name or password is required). Every page includes a link to the home page in addition to the alternative links a visitor might choose. Furthermore, to tempt the user into staying longer, we added some gift pages hidden in a deep level of the structure, toward the leaves.

LIMITATIONS OF OUR APPROACH

There are cases in which an HTML rearrangement is not feasible, because the structure of the Web server follows the dictates of logical restrictions. For example, take the case of a site used as a lyrics archive. The initial page would be a table of contents (A-Z, where A leads to all artists whose names start with A, and so on); the leaves of the HTML tree would be the songs of each artist. Even if a particular song has substantially more accesses than the others, it cannot become the root of the HTML tree, because this would make navigation to the rest of the lyrics unjustifiably problematic.

So Web page content is also important, and the administrator should consider it in page rearrangement. Soala 2.0 tackles such problems by enabling the administrator to define stable nodes and stable connections, as illustrated in Figure 2. If the administrator defines a connection as stable, the connected nodes cannot be interchanged. The

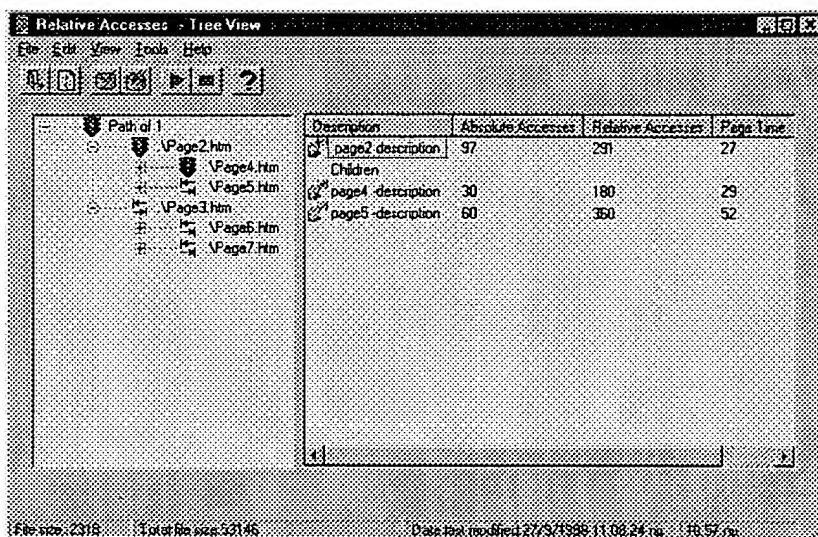


Figure 2. The link-editing interface for the Soala software. With a simple mouse click, the user can define whether a node—or a link between two nodes—is stable. The interface uses four icons to indicate the current state of each node and link. In addition, the GUI gives the user a visual representation of the HTML structure. Clicking on a specific node gives the user detailed information about and a description of that node and its immediate relatives.

Table 4. Theleis site: access measurements before and after link editing.

Site	Number of absolute accesses	Average page time (in seconds)
Initial	13,305	6.5
Revised	15,168	7.2

same applies to a stable node; it cannot be interchanged with any of its parent or child nodes.

Another side effect of any link-editing algorithm is that changing the positions of the HTML pages can render links from external sites (such as search engines, subject catalogs, and so on) out of date. Such broken links can be annoying for Net surfers, and the administrator should bear this effect in mind, especially if the link-editing algorithm is executed frequently and results in the replacement of many useful pages.

D. Ingham and colleagues have proposed an object-oriented approach to defeat broken links,⁴ and F. Kappe has proposed a server update protocol to propagate update information.⁵ There is a much easier method, however, that demands little effort from the Web administrator. During the link-editing procedure, the Soala software can map

LINK EDITING FOR GRAPH SITES

In our case study, we assumed a binary-tree structure for evaluation purposes only. Our link-editing algorithm works just as well reorganizing a graph site, which permits all kinds of links—nodes with links to a sibling node, an ancestor, and so on. Figure A shows the reorganization of a graph site.

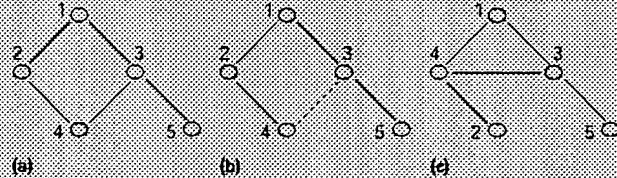


Figure A. Reorganization of a graph Web site. (a) Before we apply our link-editing algorithm, we assign each node a unique id number. Node 4 (the node with id = 4) is linked with both node 2 and node 3, but node 2 is regarded as its parent, because it has a lower id than node 3. (b) During execution, the algorithm ignores the link between node 4 and node 3. (c) When the rearrangement is complete, the algorithm reestablishes the link between nodes 4 and 3.

the URLs of the pages being replaced and their new URLs and put them into a database (either a relational database or a simple file accessible from the Web server). Then, the administrator can specially configure the error handler to check this database when a user pursues a nonupdated external link. (See <http://www.apache.org/docs-1.2/custom-error.html> for information on how to configure the Apache Web server to handle such error conditions.) Instead of returning the "404 Not found" message, the error handler determines whether the outdated link has been replaced by another one during link editing. If this page exists in the database, a message informs the user of its new URL and automatically redirects the browser to point to the new location of the page. If the file does not exist, the browser displays an error message. In this way, even if the link-editing algorithm has modified all the Web server's pages and changed their URLs, there will be no broken links, even on references from search engines.

To reduce the additional load on the Web server caused by execution of the error script handler, we advise the administrator to resubmit the home page URL to the search engine so it can update its links. The update will be available to all network

users after the search engine's reorganization interval, usually a month.

CONCLUSION

An awkward arrangement of an HTML tree can discourage a potential Internet user from visiting and staying at a specific Web site. We have shown how a link-editing algorithm can automatically fix a poor organization by calculating each page's relative popularity. Even a simple approach using relative page popularity—the combination of our equations 1 and 2—leads to a substantially enhanced scheme.

In this article, we considered only cases where the objective is to make it easier for a user to find the requested data: the faster the access, the better the organization of the Web server. But what if a Web site contains commercial material—advertisements and so on? In this case, the objective may be different: the best organization may be one that achieves the highest AA for those pages with a commercial interest. In these cases, we can associate a weight factor w with each page and modify the link-editing algorithm so that it promotes pages with a higher w more vigorously. We have developed a version of our link-editing algorithm to handle this association. A beta version, still under evaluation, has returned encouraging results.

Surely there are many different approaches to rearranging links between pages and many different ways of perceiving the notion of popularity. For example, we could give coefficient a a more complicated definition than that given in equation 2, or we could rearrange the initial page structure using a more sophisticated method than our link-editing algorithm. Nevertheless, the approach we presented in this article should not be underrated; besides being easy to analyze, it has also proved adequate in most cases, considering the percentage increase in page accesses. A link-editing algorithm that could add new links and discard others (in addition to interchanging pages) would probably demonstrate a better enhancement.

Our team is still in the process of identifying several new variables that affect Web page popularity. We will make our new results available as soon as they are extracted. ■

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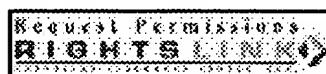
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Abstract

Awkward arrangement of documents in an **HTML tree** can discourage users from staying at a Web site. The authors have developed an algorithm for dynamically altering the organization of **pages** at sites where the main design objective is to give users fast access to requested data. The algorithm reads information from the **HTTP log file** and computes the relative popularity of **pages** within the site. Based on popularity (defined as a relationship between number of accesses, time spent, and location of the page), the hierarchical relationship between **pages** are rearranged to maximize accessibility for popular **pages**

Index Terms**Inspec****Controlled Indexing**[Internet](#) [hypermedia](#) [markup languages](#) [information resources](#) [user interfaces](#)**Non-controlled Indexing**[HTML](#) [HTTP log file](#) [Web site optimization](#) [data access](#) [hierarchical relationship](#) [page organization](#) [page popularity](#)**Author Keywords**

Not Available

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3. [SOALA](#), Tech. Report CTI-TR98.3.16, Computer Technology Inst., Patras, Greece, 1998.
4. D. Ingham et al., "W3Objects: Bringing Object-Oriented Technology to the Web," *The Web J.*, Vol. 1, No. pp. 89-105.
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Sidebar A References

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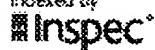
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Refine Search

Search Results -

Terms	Documents
L6 and trees	3

Database: US Pre-Grant Publication Full-Text Database
 US Patents Full-Text Database
 US OCR Full-Text Database
 EPO Abstracts Database
 JPO Abstracts Database
 Derwent World Patents Index
 IBM Technical Disclosure Bulletins

Search:

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DATE: Friday, December 02, 2005 [Printable Copy](#) [Create Case](#)

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side by side

Hit Count **Set Name**

result set

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<u>L6</u>	L5 and pages	14	<u>L6</u>
<u>L5</u>	L4 and ("hypertext markup language" or "html")	14	<u>L5</u>
<u>L4</u>	L3 and (crawl\$ or spider\$)	27	<u>L4</u>
<u>L3</u>	L1 and (suction or buy\$ and sell\$ or bidd\$ or cross-sell\$) near sites	254	<u>L3</u>
<u>L2</u>	L1 and (suction or buy\$ and sell\$ or bidd\$) near site	254	<u>L2</u>
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END OF SEARCH HISTORY

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Search Results -

Terms	Documents
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Database:

US Pre-Grant Publication Full-Text Database
 US Patents Full-Text Database
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L7 '6526424'.pn. 1 L7

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L5 L4 and ("xml" or "extensible markup language") 61 L5

L4 L3 and (page with trees or page near trees or page adj trees) 128 L4

L3 L2 and ("html" or "hypertext markup language") 1714 L3

L2 (crawl\$ or spider\$) 102154 L2

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END OF SEARCH HISTORY

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Term:	<input type="text"/>
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Search History

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L5 L4 and (enterprises or organizations or companies)

134 L5

L4 L3 and exchange

135 L4

L3 L2 and (class or category) near2 (items or products or merchandise)

146 L3

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342 L2

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